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Agile Implementation of Virtual Reality in Learning Factories

Thomas Riemann[a,*], Antonio Kreß[a], Lisa Roth[a], Sven Klipfel[a], Joachim Metternich[a], Petra Grell[a]

[a]*Technische Universität Darmstadt, Otto-Berndt-Str. 2, 64287 Darmstadt, Germany*

Abstract

The concept of learning factories fulfills current learning theoretical requirements in terms of the situation, process orientation, as well as authenticity. Nevertheless, due to the high complexity of the industrial production environment, it is challenging to transfer learned skills into the operational application situation. With Virtual Reality, training participants have the ability to learn with transfer-oriented action tasks in virtual space directly after the training in physical learning environments. The learning process can be personalized and adapted in the virtual learning environment. Each participant in the training can individually determine elements of the learning situation. For example, the entire learning environment can be adapted to the individual real production environment of the training participant. Through Virtual Reality, new forms of reflection are possible, e.g. recording the learning process. Technical, didactic and organizational requirements were identified by a systematic literature analysis. The research project is based on training courses in the process learning factory "Center for industrial Productivity" (CiP) located at TU Darmstadt. In order to assess and prioritize the requirements, expert surveys were conducted. The surveys are based on the Kano model in order to classify requirements. Must-be quality requirements are implemented in a minimum viable product (MVP). The MVP allows fast learning by testing and experimenting. Based on the agile manifesto, further requirements can be implemented agilely in the virtual environment.

Keywords: Virtual Reality; Learning Factory; Agile Project Management; Learning Scenario; Kano Model

* Corresponding author. Tel.: 49 6151 16-20106; fax: +49 6151 16-20087.
E-mail address: t.riemann@ptw.tu-darmstadt.de

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1. Introduction

For many companies, the development of underlying competencies is becoming increasingly important. Between 1991 and 2016, participation in training increased from 37 % to 50 % of the labor force in Germany [1]. The technical and methodological competencies of employees are a key competitive factor. Learning factories became very popular to develop competencies of students and employees in a realistic production environment [2]. Virtual Reality (VR) expands the possibilities and areas of application in learning factories [3]. Recent research has revealed that VR offers many opportunities in the field of education [4]. Still, only a few learning factories have implemented training scenarios in VR. The approach presented in this publication aims to close this gap so that requirements can be systematically identified, classified and evaluated.

The main objective of this paper is the presentation of evaluated requirements for the implementation of VR in learning factories. In the first step, requirements are identified through a systematic literature research. To figure out essential requirements an evaluation based on the Kano model is conducted [5]. Therefore, the paper is divided into five sections: After reviewing the basics of learning factories and VR in the field of education (section 2), the methodology of the systematic literature review and the Kano model is presented (section 3). Finally, conclusions are drawn and the results are summarized (sections 4 and 5).

2. Virtual Reality and Learning Factories

In recent years new learning technologies are applied more frequently in vocational education and training. Learning environments in VR are also increasingly used in these two fields as an instrument of further education [6]. VR is defined as interactive computer-aided simulated settings of reality [7]. For example, VR technology is used for training measures for the operation of aircraft [7]. Virtual settings in the form of VR open up new learning spaces. The immersive moment enables with the help of a head-mounted display a complete immersion into the virtual world. The learners have the feeling of being able to move physically real in it. Immersion describes the state in which the illusion moves into the background so that the virtual world is perceived as real [8]. In VR, it is possible to train specific action sequences that are difficult to test in reality. Experiences that are limited or difficult to experience can also be presented well. VR brings flexibility to time and place. For example, historical moments can be simulated [4]. With VR, it is possible to address different types of learners simultaneously [9]. Not only visual stimuli but also haptic and auditory stimuli are possible through the presentation of learning scenarios in VR. Virtual worlds reveal exploration, training and construction worlds for learners [7]. In exploration worlds, learners explore various subject areas that were previously inaccessible. The VR environment provides learners with flexible access. Training worlds aim is to acquire action-related skills and abilities. In construction worlds, learners explore the virtual world self-directed and can construct own objects in VR and also own virtual worlds [7]. The learners interact self-controlled with the virtual world. There are numerous potentials of VR for further education. However, new technology is also associated with challenges. In particular, the literature lacks detailed explanations of media didactic concepts regarding VR [10]. Similarly, the requirements placed on educational staff are changing when digital media are used in the teaching and learning process. The use of VR contributes to the fact that the transfer of knowledge by the teacher is no longer in the foreground. The role of the teacher has changed. The teacher acts primarily as a coach and supports the learning process [6,11].

In learning factories, “learning” takes place in a realistic “factory” environment [2]. Learning factories are used for teaching, training, and research. Training participants can perform actions within a real value chain of a physical product. A sustainable operating model ensures the continuous operation of the learning factory. The learning content can be experienced and reflected based on a didactical model. For this reason, learning factories offer many advantages over traditional approaches like lectures. However, the concept of physical learning factories is also limited [12]. Resources are limiting factors for a learning factory: Personnel, machines, and workstations can be cost-intensive and can require a high budget. Physical learning factories are built on a specific location and are therefore not mobile. Moreover, the mapping abilities of learning factories are limited: frequently learning factories represent single value chains of products without much flexibility. The number of training participants is also limited. Because of these limitations, virtual learning factories have been developed in the last couple of years [13].

Virtual learning factories represent digital models of learning factories. They are defined as learning factories in the broader sense [14]. Learning takes place in a virtual environment supported by head-mounted displays and software tools with a lot of options for adaptivity [15]. Depending on the operating model, training in virtual learning factories is not location or time specific and can be conducted on every time from everywhere. The number of training participants is generally not limited. Processes can be displayed in slow or in fast motion. Furthermore, a high number of value chains can be represented with different products, depending on the wishes of the training participants. The level of difficulty of the exercises can be varied according to the participants' needs. The didactical concept can be enhanced by another type of reflection: after a practical exercise, the participants can reflect from the virtual space using a recording function. The concept of a hybrid learning factory combines the advantages of the physical and the virtual environment [2]. Training can be conducted in a real or a virtual environment depending on their purpose. This opens up various possibilities for extending the existing operator model. To design learning factories, three conceptual design levels and two didactical transformations have to be considered [16]:

- The macro-level includes the infrastructure of the learning factory and the curriculum. For virtual learning factories, the macro-level includes the virtual environment with virtual representations.
- The meso-level includes learning modules. This is also the case for virtual learning factories.
- The micro-level includes teaching-learning scenarios, which are represented virtually in a virtual learning factory

In the first didactical transformation, the intended competencies are derived from the organizational environment, the organizational targets, and the target group. The second didactical transformation derives the socio-technical infrastructure and didactical aspects from the intended competencies [16]. This systematic approach can also be applied to virtual learning factories while considering new requirements.

In the research project "Virtual action tasks for personalized adaptive learning" (PortaL) a personalized training scenario is developed in VR. The focus is on adapting and personalizing the learning process. After a training course, in the physical learning factory, the participants conduct a personalized exercise in the virtual environment. The developed approach will initially be implemented in the Process Learning Factory CiP using the example of an existing training course. The division UReality of Kirchner GmbH develops the software agilely for the virtual environment. First, a minimum viable product is developed in which the most important requirements are implemented. The training scenario is tested and evaluated multiple times by conducting the training scenario with several partner companies. The virtual environment improves with each test. In addition, a guideline will be developed to implement virtual exercises for different target groups, training formats, and learning content.

3. Methodology

Agile management provides methods to react fast to changing conditions. Therefore, agile methods are widely used. Based on the agile manifesto individuals and interactions (over processes and tools), working software (over comprehensive documentation), customer collaboration (over contract negotiation) and responding to change (over following a plan) are focused [17]. The methodology of this paper (see Fig. 1) is based on the agile framework. Identified requirements are saved in a product backlog [18]. Must requirements are realized in a minimum viable product that will be improved iteratively with user tests [19]. To determine the category of all requirements, the requirements are classified with the Kano model [20]. Before the implementation, the classified requirements are sequenced considering implementation effort and dependencies between requirements. User tests of the current virtual environment allow the identification of new and changing requirements, which have to be adjusted. This paper focuses on the identification and classification of requirements (steps 1 and 2 in Fig. 1).

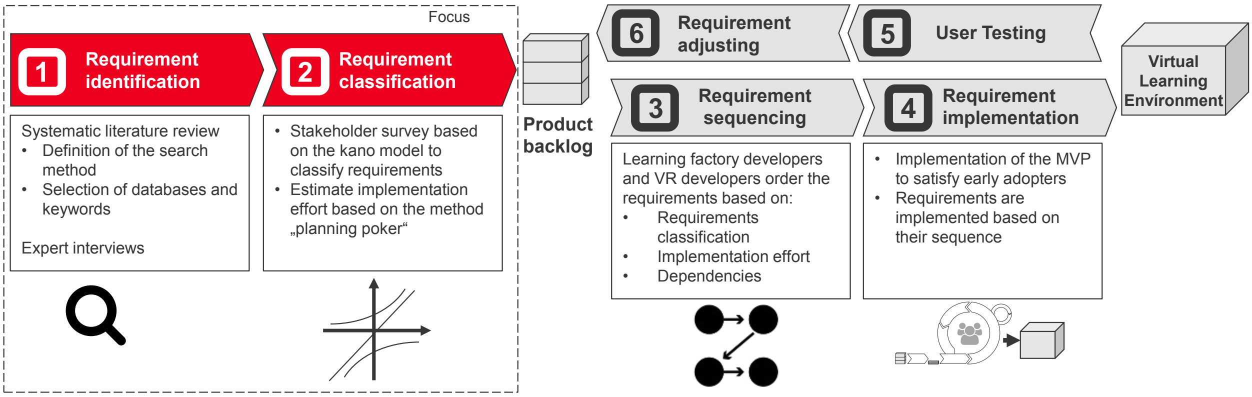

Fig. 1. Approach for the identification and implementation of product requirements within the research project PortaL.

Within the implemented systematic literature research, German and English literature from 2013 to 2019 was considered [21]. For this purpose, a full-text search was carried out in various databases using predefined keywords. Only full-texts containing the terms "virtual reality" and "learning factory" or synonyms of both terms were taken into account [22]. After a three-stage screening process, in which firstly the headings and secondly the abstracts of the identified literature were checked for their suitability, 46 texts were reviewed in detail for requirements. As a result of the systematic literature search, 41 requirements were identified and assigned to three categories (technical, didactic and organizational). 39 out of the 41 requirements could further be classed thematically into eleven thematic target groups, such as feedback/support (9 require ments), individuality (7 requirements) or safety (3 requirements). For example “individuality”: a target for courses in virtual reality are individualized training contents for the learner through an adaptable environment. The classification into categories and thematic target groups enabled a well-structured list of requirements to be compiled. For the Kano survey, the requirements were further selected and summarized, leaving 26 attributes leftover (see Table 1). The product attributes were derived from the requirements.

Table 1. Sample excerpt from the created requirements list (T = Technical, D = Didactic, O = Organisational; ○ = not assignable, ◑ = partially assignable, ● = fully assignable).

Target	Requirement	Explanation	Source	Requirementclass		
				T	D	O
Individuality	Adjustable level of difficulty	Simplifications when participants lack the necessary know-how	Plorin et al. (2015) [23]	○	●	○
Feedback/ support	Virtual trainer	Expert to assist the user whenever questions arise, or if the user does not know any further.	Weidig et al. (2014) [24]	●	●	○
Practice-orientation	Realistic tasks	“Learning factories […] challenges comparable to those of real factories.”	Ullrich et al. (2019) [25]	◑	●	○
Team	Multiplayer mode	Possibility to collaboratively work with other course participants on team tasks in VR	Posada et al. (2018) [26]	●	●	◑
⋮	⋮	⋮	⋮	⋮	⋮	⋮

The Kano model was developed to classify product attributes into different categories in order to satisfy customer needs. The product attributes can be classified within the model in a total of five attribute categories [5]:

(1) Must-be: these do not lead to satisfaction but the absence of these attributes leads to dissatisfaction.
(2) One-dimensional: these lead to satisfaction when fulfilled and to dissatisfaction when not fulfilled
(3) Attractive: these lead to satisfaction when fulfilled, but absence does not lead to dissatisfaction.
(4) Indifferent: these lead neither to satisfaction nor dissatisfaction, whether fulfilled or not.
(5) Reverse: these work opposite to the attractive attributes. The fulfillment of these attributes leads to dissatisfaction, but the absence of these attributes does not lead to satisfaction.

The categorization into the different categories takes place using functional and dysfunctional questionnaires, on which the individual aspects are evaluated on a five elementary Likert scale [5]. Exemplary questions for an attribute would be:

(1) If the product attribute X is fulfilled, how would you like this?

(2) If product attribute X does not exist, how would you like this?

In the context of this scientific work, the requirements for the virtual reality software product identified based on the structured literature research were classified into the various categories of the Kano model. Questionnaires with the developed positive and negative questions were distributed to a total of 24 participants from the participant groups learning factory trainers and learning factory training participants as well as students.

4. Results

Of a total of 26 product attributes, 17 were rated as attractive attributes, 1 as one-dimensional attributes, 4 as must-be attributes and 4 as indifferent attributes (see sample excerpt in Table 2). Interestingly, none of the surveyed attributes could be classified as a reverse attribute based on the survey results. The survey of the participants revealed the following result for the exemplary presented requirements: the training participants and trainers classify the attributes of a virtual trainer, the multiplayer mode and different difficulty levels as attractive attributes. In the context of realistic tasks, supportive information, and support from trainers, the attributes were assessed as must-be attributes of the software product. For the survey group of the trainers, the possibility of cost reductions in comparison to conventional courses in the learning factory is a one-dimensional attribute. Multimodal feedback and a recognizable environment were evaluated as indifferent attributes. The category strength is given in brackets: attributes with a category strength ≥ 0.06 are considered as clearly classified [27].

Table 2. Categorization results based on the participant and trainer survey.

<table>
<tr><th>Must-be</th><th>One Dimensional</th><th colspan="2">Attractive</th></tr>
<tr><td rowspan="3">• Intuitive usability (.58)
• Realistic tasks (.16)
• Supportive information (.13)
• Support from the trainer (.00)</td><td>• Cost reduction (.00)</td><td rowspan="3">• Realistic haptics (.53)
• Multiplayer mode (.50)
• Supports innovative actions (.45)
• Visual hints (.38)
• Encourages to test limits (.33)
• Different difficulty levels (.29)
• Different scenarios (.29)
• Multimodal input (.26)
• Continuous feedback (.25)</td><td rowspan="3">• Supports learners self-management (0.21)
• Gamification elements (.13)
• Supportive 3D animations (.13)
• Accessibility features (.10)
• Virtual trainer (.06)
• Warns users (.06)
• Additional real training (.04)
• Supports different learning speeds (.04)</td></tr>
<tr><th>Indifferent</th></tr>
<tr><td>• Acoustic feedback (.38)
• Multimodal feedback (.25)
• Security guidelines (.21)
• Recognizability of the environment (.06)</td></tr>
</table>

5. Conclusion and outlook

In this paper, requirements for implementing VR in learning factories are identified and classified. To identify the requirements, a systematic literature review is conducted. Four exemplary requirements for the integration of VR in learning factories were presented, e.g. an adjustable level of difficulty for the practical exercise in VR. The requirements are classified with the Kano model in a survey. As a result, the requirements could be classified in “one dimensional”, “attractive”, “must-be” and “indifferent” attributes. Future research will examine the results of user testing. User testing reveals which functionalities are used by the training participants, how they are used and whether any functionalities are missing. Based on this, a guideline will be developed with which personalized VR exercises for learning factories can be designed. In the future, it will be possible to conduct a value stream analysis in a personalized VR exercise in the process learning factory CiP.

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